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GIFFORD PINCHOT, Forester.

KILN-DRYING HARDWOOD LUMBER.

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KILN-DRYING HARDWOOD LUMBER.

DIFFICULTY OF DRYING WOOD.

The special precautions necessary to prevent loss of strength or distortion of shape render the drying of wood especially difficult. In drying chemicals or fabrics, all that is required is to provide heat enough to vaporize the moisture and circulation enough to carry off the vapor, and the quickest and most convenient means to these ends may be used. In drying wood, whether in the form of standard stock or finished product, the application of the requisite heat and circulation must be carefully regulated thruout the entire process, or warping and checking are almost certain to result. Moreover, wood of different shapes and thicknesses is very differently affected by the same treatment. Finally, the tissues composing the wood, which vary in form and physical properties, and which cross each other in regular directions, exert their own peculiar influence upon its behavior during drying. With our native woods, for instance, summer wood and spring wood show distinct tendencies in drying, and the same is true in less degree of heartwood as contrasted with sapwood. Or, again, pronounced medullary rays further complicate the drying problem. Plain oak and quartered oak require different treatment. Even in mahogany and similar tropical woods which are outwardly more homogeneous, various kinds of tissue are differentiated.

THE WATER IN WOOD.

In the living tree and in green wood there is a large amount of water. Part of this is closely held in the material of the cell walls, and can not be removed without affecting the physical condition of the wood; the rest, which fills the pores of the wood, is free water. In drying, the free water within the cells passes thru the cell walls until the cells are empty, while the cell walls remain saturated. When all the free water has been removed, the cell walls begin to yield up their moisture. Heat raises the absorptive power of the fibers, and so aids the passage of water from the interior of the cells.[a]

[a] The investigations of Tiemann have shown that the free water is first removed in drying. The point at which the free water is exhausted in drying, or, conversely, the point beyond which the wood fibers can take up no more moisture, he designates as the fiber-saturation point. (See "The Effect of Moisture on the Strength and Stiffness of Wood," Bulletin 70 of the Forest Service, U. S. Department of Agriculture.)

A confusion in the use of the word "sap" is to be found in many discussions of kiln-drying; in some instances it means water, in other cases it is applied to the organic substances held in a water solution in the cell cavities. The term is best confined to the organic substances from the living cell. These substances, for the most part of the nature of sugar, have a strong attraction for water and water vapor and so retard drying and absorb moisture into dried wood. High temperatures, especially those produced by live steam, appear to destroy these organic compounds, and therefore both to retard and to limit the reabsorption of moisture when the wood is subsequently exposed to the atmosphere.

Air-dried wood, under ordinary atmospheric temperatures, retains from 10 to 20 per cent of moisture, whereas kiln-dried wood may have no more than 5 per cent as it comes from the kiln. The exact figures for a given species depend in the first case upon the weather conditions, and in the second case upon the temperature of the kiln and the time during which the wood is exposed to it. When wood that has been kiln-dried is allowed to stand in the open it apparently ceases to reabsorb moisture from the air before its moisture content equals that of wood which has merely been air-dried in the same place and under the same conditions.

KILNS AND METHODS STUDIED.

WOODS.

The studies upon which this report is based covered the following woods: White oak, red oak, maple, birch, basswood, chestnut, ash, red gum, mahogany, cherry, and walnut.

TIME REQUIRED.

The time consumed in drying, one of the most important items in the expense account, varies very widely among operators. Take, for example, 1-inch plain white oak, which is a standard material dried thruout the region studied. As a rule, this is dried from one to two weeks, yet many operators, even when crowded for kiln space, double this period, whereas at the larger and more progressive plants, especially those drying hardwood flooring, it is reduced to five, four, or even three days. Where the kiln is larger than necessary it is a not uncommon practise to use it as a storage room for surplus stock.

The time of drying differs widely also with the species, as well as with the intended use. Quarter-sawed oak usually requires half again as long as plain oak. Mahogany requires about the same time as plain oak; ash dries in a little less time, and maple, according to the purpose for which it is intended, may be dried in one-fifth the time

needed for oak or may need a slightly longer treatment. For birch the time required is from one-half to two-thirds, and for poplar and basswood, from one-fifth to one-third that required for oak.

COST.

The information secured upon cost indicates—especially among smaller operators, where economies are less carefully studied—the widest divergence. The extreme figures, for products not widely different, are 75 cents and $5 per thousand feet.

USE OF KILN-DRIED WOODS.

With the exception of structural timber, nearly all hardwoods are kiln-dried before they are made into the finished product. A surface finish such as that demanded in furniture and interior work and the high degree of strength and stiffness demanded in vehicle and implement stock are impossible without thoro drying, and this drying is most quickly accomplished in a kiln. For the very exacting requirements of wheel work and of shoe-last and printing-type wood rapid kiln-drying has not yet proved entirely satisfactory, but new and improved methods appear to promise success.

DEFECTS OF PRESENT METHODS.

Dry kilns are at present constructed and operated largely without thorogoing system. Forms of kiln and modes of operation have commonly been copied by one woodworking plant after the example of some neighboring establishment. In this way it has been brought about that the present practises have many shortcomings. The most progressive operators, however, have experimented freely in the effort to secure special results desirable for their peculiar products.

RESULTS OF MISTREATMENT.

Mistreatment of the material results in numerous defects, chief among which are warping and twisting, checking, casehardening, and honeycombing.

Many woods, as, for example, tupelo and red gum, will warp and twist in drying unless special care is taken. This difficulty is not confined to kiln-drying, but is quite as great in air-drying. Indeed, drying in the open with exposure to the sun often develops the worst examples. In both cases the remedy lies in proper piling. In piling lumber for the kiln the cross sticks should always be placed directly over the trucks, following a perpendicular line. Where the intervals between trucks are so great that intermediate sticks are required, heavy timbers

should first be laid upon the trucks, to form a foundation for the pile. It is a good practise to place sticks at the very end of the pile. (See fig. 1.)

If the kiln-drying is too rapid the lumber may open up at the ends in deep checks. This defect is common to all grades of veneer stock and is most conspicuous in thin hardwood veneers. Frequently checks which appear after kiln-drying were originally formed during previous air-drying and are merely reopened in the kiln. These may readily be distinguished from fresh checks formed in the kiln, since their inner surfaces have been filled with dust and darkened by the weather. It appears to be almost impossible to prevent their reopening.

Casehardening occurs when the kiln-drying is pushed too rapidly without proper precautions. The surface of the wood becomes dry

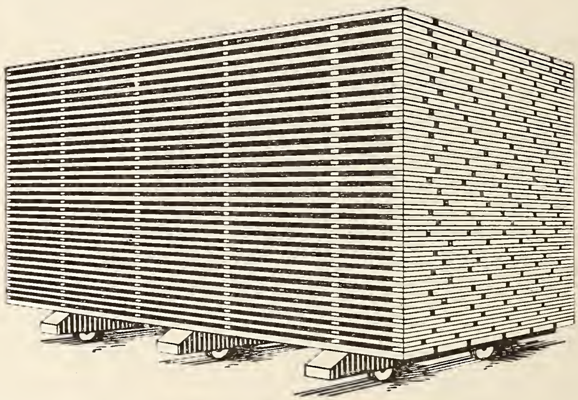

Fig. 1.—Correct way to pile timber liable to warp in drying. Place upon the trucks a foundation of 2-inch planks. The sticks are to be laid one directly over the other, and one tier should be at the very ends of the boards, or it may even project beyond the ends to prevent too rapid drying at this point. As far as practicable, place the sticks directly over the trucks. This is much more important where heavy foundation planks are not used.

and impervious, while the interior remains almost as moist as before.[a] Thoro drying is thus quite prevented, and effort to secure it usually produces honeycombing.

Honeycombing can occur only together with casehardening. It is, in effect, internal checking in which the checks, following the medullary rays, may run nearly from end to end of the piece but do not, except in extreme cases, show upon the surface. In figure 2 are shown cross sections of a quarter-sawed plank in which the honeycombing is so extensive that the surface is visibly deprest. Woods with conspicuous medullary rays are most subject to this defect.

[a] Casehardening is more fully discust on pages 116 to 118, Bulletin 70 of the Forest Service, "Effect of Moisture on the Strength and Stiffness of Wood."

THEORY OF DRYING.

Despite the diversity of practise, it is possible to find among the larger and more enterprising operators a measure of agreement, as to both methods and results, and from this to outline the essentials of a correct theory.

Before any drying occurs both the wood and the water it contains must be raised to the temperature at which the drying is to take place. If the wood is slowly heated and circulation is meantime suffered to carry off the surface moisture as fast as it is vaporized, the surface becomes entirely dry before the internal moisture is even moderately heated or has begun to move in quantity to the surface. Moreover, if preliminary air-drying has taken place, it should be remembered that more moisture has been lost from the surface than from the interior and that it is important that this condition should

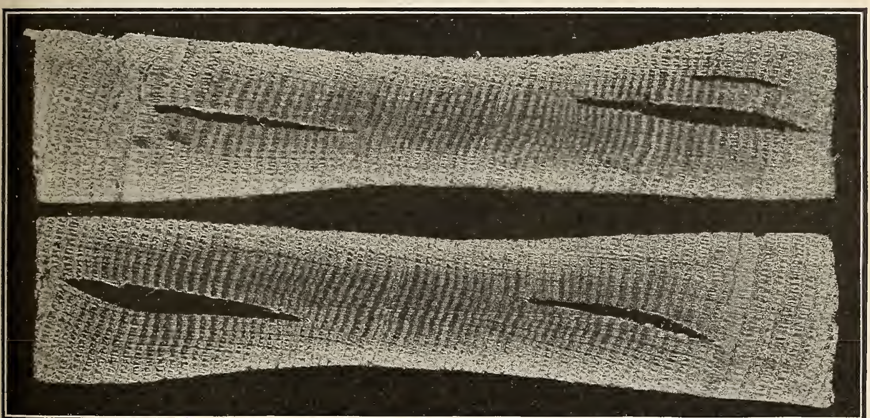

FIG. 2.—Honeycombing in thick quartered oak.

not be accentuated in the kiln. It is necessary, therefore, that surface-drying be delayed in the kiln by retaining the moisture first vaporized about the wood while the continued heat penetrates to the internal moisture. Thus far this is essentially the moist-air system of drying. Steam may be used to advantage to wet the wood, and tho this increases the water content it shortens the time required for drying by quickly raising the wood to the drying temperature.

When once the wood has been raised to a high temperature thru and thru, and especially when the surface has been rendered most permeable to moisture, drying may proceed as rapidly as it can be forced by artificial circulation, provided the heat lost from the wood thru vaporization is constantly replaced by the heat of the kiln.

The drying is actually carried out by admitting hot, unsaturated air to contact with the heated wood and replacing it constantly as it

becomes saturated. The best rate of circulation for the air, as well as the best degree of humidity, is still unsettled. Provided the internal moisture is kept moving toward the surface as rapidly as the surface moisture is removed, the problem of hastening the drying by increasing the circulation and regulating the humidity is comparatively simple. It should be quite possible to discover by simple experiments what means of fulfilling the conditions are suited to the drying of lumber on a commercial scale.

Successful kiln-drying depends chiefly upon these two principles and upon keeping separate the two distinct stages of the process which they govern.

To carry out right drying principles a rightly constructed kiln is necessary. The essentials of kiln construction, deferring details for the present, include the following points:

The system of heaters and radiators should be capable of maintaining the desired temperature at all times.

The temperature and humidity of the drying chamber should be under perfect control and protected from outside influences.

Simple devices should control the circulation as desired, both between the kiln and the outer atmosphere and between the two ends of the kiln.

Toward the end of the process abundant and vigorous circulation should be provided for, due care being taken not to lower the temperature.

THE DRY KILN.

TYPES.

As regards construction there are two general types of dry kilns. In the radiator kiln (fig. 3) the timber is heated by coils of steam pipes under the floor; in the blower kiln (fig. 4) heat is supplied by a current of air heated outside the kiln and forced in by a fan.

The common designations are "hot-blast" and "moist-air" kilns, but these refer to methods of operation rather than to construction. Moist-air kilns, whether of the blower or the radiator type, are managed on the moist-air principle.

PARTS.

The essential parts of a dry kiln are the drying chamber, the steam coils, and the ventilating device.

The drying chamber varies greatly in length, according to the output desired and the process used. It may be as short as 15 feet or as long as 150 feet. In most cases its height is from 6 to 8 feet, with a width of from 10 to 30 feet. Tho it may be made of a number of materials, wood is widely used where the building laws permit.

The choice of material depends otherwise upon the kind of lumber to be used and the thoroness of drying desired. Some of the best drying is done in brick kilns with concrete foundations.

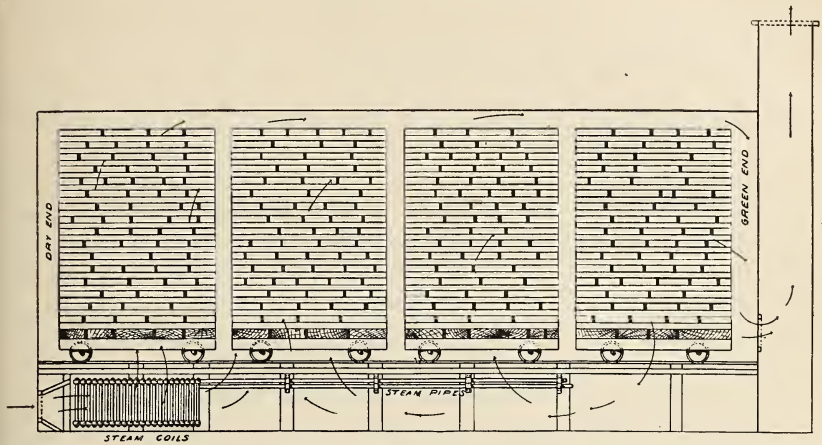

FIG. 3.—Scheme of a radiator kiln, known on the market as a "moist-air" kiln. The kiln represented is designed for progressive operation. The ventilator shaft at the right is often dispensed with. Arrows indicate the general direction of the air currents.

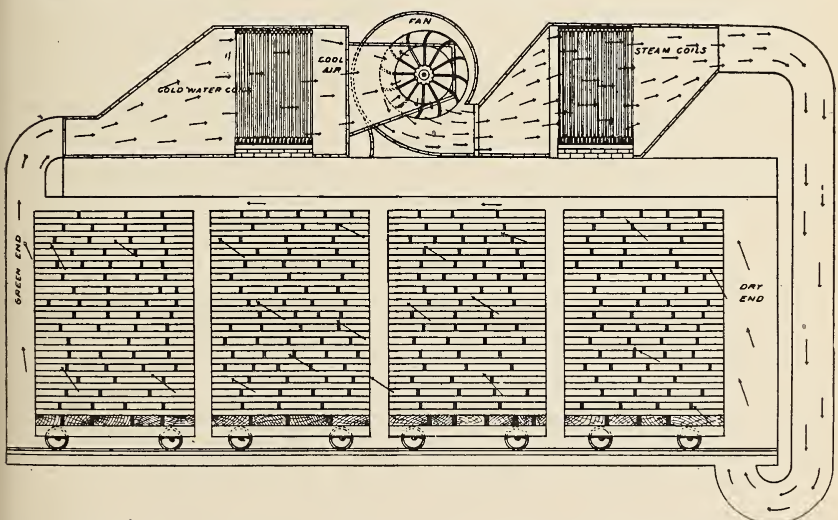

FIG. 4.—Scheme of a "blower" kiln using return air to maintain the desired humidity in the kiln. Saturated air is drawn from the green end of the kiln thru cold-water coils, where it is cooled and made to deposit part of the moisture it contains. Passing thru the fan, it is heated in the steam coils and made relatively drier. At the dry end of the kiln this heated air removes the last remaining moisture from the lumber. By varying the temperatures in the cooling and in the heating coils the conditions in the kiln may be regulated very accurately.

The steam coils which furnish the heat have various forms in both types of kilns. In the radiator type they extend under the floors from the "dry" end of the kiln part way or all the way to the opposite end. They may be of single, double, or treble thickness of inch

pipe, according to the heat required. To secure provision for their contraction and expansion, and for their drainage, special attention is given to their installation. In the blower type of kiln there are no steam pipes in the drying chamber itself; the heat is supplied by air heated outside and forced into the kiln by a fan.

To maintain in the kiln the circulation of air needed in drying, there are a number of devices, of which the simplest is possibly a system of ventilator shafts for removing the lighter moist air from the top of the kiln. In blower kilns a fan is used for the same purpose, and in some radiator kilns in which the humidity is kept very high the only outlets are heavy dampers thru which the air must force its way. There are certain makes of both radiator and blower kilns operated on the moist-air principle, which are equipped with condensing chambers for the removal of a portion of the moisture from the air.

Doors are made of a number of materials, of which canvas and wood are most widely used. The doors are never hinged, but slide along a track or in grooves, or are counterbalanced so as to be thrown up like windows.

The lumber is carried thru the chamber on trucks holding from one to three thousand feet, or even more. These are usually of steel bars, 6 feet long, with a wheel at each end. According as there are two or three tracks in the kiln, two or three of these trucks are used. In piling the lumber upon them the pieces are not placed in contact, but, as in piling for air-drying, are "stuck"—that is, held separate above and below by inch strips laid crosswise.

COMMON FAULTS.

Too often kilns are badly planned as regards either arrangement of parts or connection with the mill, in this way adding needlessly to both the cost of operating and regulation of heat and circulation. Not infrequently steam is wastefully cooled by being carried farther than necessary across the yards to the kiln, or the kiln is isolated and exposed to the winds, so that the highest temperatures, whenever desirable, can not be maintained. Again, if the openings in the top and sides are too large, circulation is excessive and it becomes impossible to preserve the high humidity which is necessary, at least for the most rapid and advantageous drying of the wood.

METHODS OF OPERATING.

There are two methods followed in kiln operation—the progressive and the charge systems. The progressive system requires a kiln of considerable length, say upwards of 50 feet. Temperature and moisture are so distributed in the kiln that in passing from the green to the dry end a load of lumber is first moistened, then heated, and

finally dried out. In this way all stages of the process are under way in the different parts of the kiln at once. Circulation may be carried on by a draft lengthwise of the kiln which carries back the moisture from the dry end of the kiln and deposits it on the wood in the wet end, or, where the extreme of moist-air drying is practised, there may be no such longitudinal circulation and very little circulation of any kind. In the latter case the humidity is very high even at the dry end. The temperature may be fairly uniform thruout the whole length of the kiln, in which case the wood must be very hot on exit to insure the removal of residual moisture, or a difference of 20° to 40° F. or more may exist between the two ends. The progressive system of operating is most widely employed in factories where the wood to be dried is of fairly even thickness and quality and where the drying is done in large amounts and continuously.

Kilns for operation in the charge system are typically square. The kiln is charged and this charge is dried before fresh material is admitted. Wheeled carriages may be used to carry the material, or it may be piled upon the floor or arranged along the walls. For novelty works and other establishments with a highly varied product of which smaller amounts are dried at once this method is widely employed, and wherever particular attention must be paid to the thickness and quality of the stock it probably yields the best results. Conditions are controlled entirely from outside the kiln and are varied to suit the operator's ideas of the requirements of the case.

Drying may be continuous or intermittent. From necessity or economy many kilns are operated only by day. At night, in such cases, the heat is shut off, the blower is stopt, and the temperature is allowed to fall, while the humidity may reach the dewpoint. Intermittent operation is not adapted to yield the best quality of product. It would be highly expensive, owing to the loss in heat in restoring the drying temperature in the morning, were it not that in this case only exhaust steam is used.

Where the drying is continuous, the kiln is supplied with live steam when the engines are shut down at night. This means that drying progresses evenly. The material is held at a regular temperature and, provided the humidity does not fall too low, checking and warping are less apt to occur.

MOIST-AIR DRYING.

It has been pointed out that moist-air drying can be carried on in both blower and radiator kilns, and that the moist-air system has the wider use. Builders of radiator kilns, however, generally advertise them as moist-air kilns and refer to blower kilns as hot-blast kilns. They lay stress on the damage done to the heavier grades of stock by treatment in a fan kiln and deprecate the use of any kiln with forced

draft. Careful study shows that as a matter of fact most successful kilns drying lumber heavier than pine and poplar are operated on the moist-air system, whether or not they are equipped with a fan. Moist air can easily be secured in blower kilns by using the saturated air as it leaves the kiln, or by admitting wet steam either into the heater itself or into direct contact with the lumber in the chamber, and in radiator kilns by merely closing the drafts and gradually raising the temperature. Tho humidity is generally secured by steam, some operators, during winter, secure it by piling snow upon the lumber as it enters the green end of the kiln. In any system of moist-air drying where no fan is used the lumber, upon coming out of the kiln, retains a residuum of moisture, which evaporates from the heated surface in the open. For this reason many operators, especially when the weather favors, or shed room is available, keep the stock exposed to the fresh air for a day or two after it leaves the kiln.

Most of the past and present improvement in the kiln-drying of lumber follows the line of moist-air operation.

PRELIMINARY SEASONING.

Hardwood lumber is commonly air-dried at the sawmill for a period of from two to six months. Present demand for lumber is, however, so great that there is strong inducement to market it as air-dried when actually it is nearly or entirely green from the saw.

To supplement the drying at the mill, or to make up for it when it has been omitted, kiln operators who are particular about the quality of their product very often pile the stock, as it comes from the cars, in their own yards, and allow it to air-dry there for a few months or even for a year or two. This yard-drying unquestionably improves the stock and indeed is indispensable for certain types of kilns. On the other hand, for kilns which yield the best results when considerable moisture is present, green material may be most suitable. It is probable that, for the sake of economy, yard-drying will be eliminated in the kiln-drying of the future without loss to the quality of the product.

The extreme form of preliminary seasoning is found in the shed-drying of stock as practised by vehicle and implement makers. Shed-drying for two or three years leaves so little moisture in the wood that the kiln-drying which follows is but a very brief process.

From shed-drying it is only a little further to the treatment given to such close-grained woods as boxwood, which is dried for wood-engraving blocks. Such blocks are wrapt in pieces of coarse gunny sack and stored in small barrels or boxes in a temperature of about summer heat, very frequently in a room directly over a kiln. After about a year the blocks are completely dried. So tedious a process can, of course, be profitable only when the product must be absolutely free from checks and other imperfections.

PRELIMINARY USE OF STEAM.

In addition to supplying heat to the kiln, steam may be used either to maintain the proper humidity in the kiln, as in certain kinds of moist-air operations, or to moisten and heat the lumber before it enters the kiln. For preliminary steaming in the progressive system of drying, a steaming chamber must be provided at the green end of the kiln; with the charge system the drying chamber may be used instead.

WET STEAM.

In preliminary treatment with wet steam, when the drying is progressive, provision is made at the green end of the kiln for a steam chamber. This may be detached from the drying chamber or may be a part of the drying chamber cut off from the rest by a wooden or canvas partition. It is large enough to hold a single truck of lumber. Under the floor there is a perforated steam pipe, usually running diagonally across the bottom. If the heat of the unconfined steam which enters thru the perforated pipe is insufficient, as may be the case if the kiln is of wood and much heat is lost, the steam radiators used thruout the kiln in heating the charge may also extend under this floor. The loaded truck is run into the steam chamber, the outer doors are closed as tightly as possible, and steam is admitted. Altho in one sense steam thus used may be regarded as live steam because the pipe conveying it runs directly from the boiler to the steaming chamber, the pressure when it is released in the chamber is reduced in effect to zero, so that it is really exhaust steam. The pressure of true live steam, tho no greater than a single pound per square inch, would destroy a chamber built of ordinary masonry.

Duration of treatment varies with different operators; it depends mainly upon the efficiency of the steaming chamber and method of drying which is to follow. The longest steaming noted in this study, thirty hours, was given where a completely detached wooden kiln was operated on the charge system. The shortest, two hours, sufficed with a concrete kiln in which a single truck load was steamed at one time, preparatory to treatment in a blower kiln equipped with condensing coils.

LIVE STEAM.

A steel retort, or boiler, capable of withstanding considerable pressure, is necessary for preliminary treatment with live steam. Tho at present not in wide use, this method appears to promise exceedingly well. It is true that when operations are on a large scale an extra handling of the lumber is necessary to move it from the steaming retort to the kiln, but the reduction of the time subsequently needed for drying is so great as to offset this and result profitably. A further saving is effected by the fact that green timber,

fresh from the saw, can be treated as readily as older stock, sometimes apparently more readily, so that preliminary seasoning may be dispensed with. In respect to the effect of live steam on the strength of wood, experiments upon loblolly pine railroad ties have shown that long treatment does produce weakness, 20 pounds pressure for four hours having been shown to reduce the strength about 16 per cent, tho a portion of this loss was regained upon subsequent seasoning.[a] It is quite certain, however, that the brief steaming preparatory to kiln-drying, which lasts only from five to fifteen minutes, will have only very slight effect, or no effect at all, on the strength of the material.

SUBMERSION IN WATER.

Prolonged submersion of wood in water is believed to prepare it well for drying. The probable reason for this is the leaching out of the sap constituents so that the cell cavities finally contain approximately pure water; for the organic sap, as we have already seen, appears to hamper the extraction of water in drying. In rafting, logs frequently remain a long time in water before they are sawed, and the lumber cut from such logs is held to dry more readily and thoroly. For the past two years the Forest Service has been conducting experiments on the influence of submersion upon subsequent air-seasoning. These experiments are not yet concluded, but present results add weight to these views. The effect of submersion upon subsequent drying varies with species and climate.

TESTING THE RESULTS.

For thoroly testing the effects of kiln-drying on the wood, methods must be employed which call for specially trained men. The quality of workability in the mill, for instance, tho hard to explain to the tyro, is readily recognized by planing-mill men, sawyers, and woodworkers generally.

Kiln-dried material should work smooth under the planer and sander; should pass thru the saw with a peculiar resonance, and should stand up to cutting edges of all descriptions with little tearing of the fiber. Improperly dried material tears out either with or across the fiber and can be given a polished surface only with difficulty. Workability is thus rather a complex quality; it is determined by the general judgment of the trained workmen handling the stock.

Differences of color, smell, and resonance, by which also the experienced kiln operator judges his stock, are almost as difficult for the layman to distinguish.

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[a] Circular 39, Forest Service, "Experiments on the Strength of Treated Timber," deals more specifically with this subject.

Measurement of shrinkage and of loss in weight forms a somewhat more scientific test for freshly kiln-dried material. For this, disks are cut from the middle of kiln-dried stock and carefully measured either with a scale or by tracing their outline, and are also weighed. The disks are then put in a hot box or placed directly on a steam pipe, with free circulation of air. After being heated for a few days to a temperature higher than that in the kiln, they are remeasured or compared with their former outlines to determine shrinkage, and reweighed to determine loss in weight. The extent to which kiln-drying has fulfilled its purpose is thus brought out.

AUXILIARY EQUIPMENT.

It is essential to know what conditions of temperature, humidity, and circulation obtain in the kiln when the output is being properly dried, since these are probably the most important and are certainly the most readily determined elements of the operation. Successful kiln-drying depends, therefore, not only upon the adequacy of the drying equipment, but also upon the auxiliary equipment for showing at every moment the conditions within the drying chamber.

THERMOMETERS.

Few kilns are unprovided with some sort of thermometer. It is almost absolutely demanded that the operator know at least the general temperature inside the kiln and have an approximate idea of the variations that occur. The ordinary form of mercurial thermometer graduated from atmospheric temperatures up to about 250° F. is the cheapest and most widely used. It is well to have at least two such thermometers in a long kiln operated progressively, one at each end; but many operators have only one, placed at the dry or unloading end. Recording thermometers are more expensive instruments and are not widely used. Where they do find use it is frequently as much to furnish information regarding the efficiency of the night fireman as to show the treatment the lumber in the kiln receives.

Two thermometers, one at the dry end, to indicate the highest temperature to which the lumber is heated, and one nearly but not exactly at the green end, to indicate the temperature gradient, make a satisfactory equipment for a progressive kiln. Placing the instrument exactly at the green end would expose it to too great variation due to the cold, undried lumber that enters the kiln and to the drop of temperature that ensues upon opening the doors. It is evident that but one instrument is necessary in a kiln which is operated by charge.

HYGROMETER.

Where a hygrometer is used the form usually employed is the direct-reading, hair hygrometer. The true efficiency of this instrument is not known, tho some calibrations appear to indicate an accuracy sufficient for the work. The immediate response of these instruments to changes in humidity is a disadvantage in a dry kiln.

Wet and dry bulb thermometers give more accurately the relative humidity at ordinary temperatures. The hygrodeik, an adaptation of the wet and dry bulb thermometers, consists of two thermometers mounted over a diagram, from which it is possible from any two readings of the two thermometers to find directly the relative humidity such readings indicate. To the admitted accuracy and reliability of the wet and dry bulb equipment, the hygrodeik adds the convenience of direct reading.

The temperature in some kilns exceeds 220° F. The wet bulb of the hygrodeik can, of course, furnish no readings above 212° F., the boiling point, and the instrument fails to give reliable results above 200° F. Since there is an increasing tendency to dry at higher temperatures, the need for a more suitable instrument is obvious.

An instrument to determine the dew-point by the deposition of a fog on a chilled surface appears to meet requirements. Introduced into the kiln such an instrument is immediately covered with moisture deposited from the humid atmosphere. As the instrument becomes warmer, however, this dew disappears. The temperature at which this occurs is the dew-point, and from it the relative humidity can be calculated.

ANEMOMETER.

A compact 6-inch anemometer, with a recording dial registering to 10,000,000 feet and repeat, is found satisfactory to measure circulation in kiln-drying. By multiplying the recorded rate in feet per minute by the area of the cross section of the duct in which the velocity is measured, the volume of the air moved per minute is obtained.

CALIPER.

For measuring the shrinkage or change in the diameter, width, or length of material in drying, a scale graduated to millimeters or to twentieths of an inch will be found convenient. A sliding arm, not unlike that of a tree caliper, will add to the rapidity and accuracy with which this instrument can be read. A steel plate with slits of the standard sizes is used to measure the thickness of veneers.

SCALES.

Spring scales of common forms will answer very well for weighing pieces of wood for determining the amount of water lost and for weighing the amount of water flowing from a condenser.

LAMP.

A small pocket electric lamp will prove very helpful. This can be carried into the dark places and under the floor of any kiln without the slightest danger of fire. It is the only form of lamp which can be safely used where electric wiring is wanting.

UNSOLVED PROBLEMS.

That the foregoing discussion of hardwood kiln-drying is incomplete is due to lack of exact information upon a number of points of more or less importance. It may prove helpful to call special attention to several of these.

Physical data of the properties of wood in relation to heat are very meager. Figures on the specific heat of wood, for instance, are not readily available, tho upon this rests not only the exact operation of heating coils for kilns, but the theory of kiln-drying as a whole.

Great divergence is shown in the results of experiments in the conductivity of wood. It remains to be seen whether the known variation of conductivity with moisture content will reduce these results to uniformity.

The maximum temperature to which the wood may be exposed without serious loss of strength has not been determined.

The optimum temperature for drying is entirely unsettled.

The interrelation between wood and water is as imperfectly known to dry-kiln operators as that between wood and heat. What moisture conditions obtain in a stick of air-dried wood; how is the moisture distributed; what is its form? What is the meaning of the peculiar surface conditions which, even in air-dried stock, appear to indicate incipient casehardening? These questions can be answered thus far only by speculation or at best on the basis of incomplete data.

Until these problems are solved kiln-drying must remain without the guidance of complete scientific theory. The Forest Service is now studying the effect of temperatures and steam pressures used in drying upon the strength of wood, and will take up other related problems as opportunity permits.

Approved:

James Wilson,

Secretary of Agriculture.

Washington, D. C., *October 8, 1906.*

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